MOISTURE AND EASTERLY MOISTURE TRANSPORT AT TRINIDAD

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ABSTRACT

Frequency distributions are presented of the liquid equivalent of water vapor (precipitable water) at 10°N., at Trinidad, W.I., derived from observations by the U.S. Navy rawinsonde station. The distributions are shown by height and by season. Frequency distributions are also presented of the transport of moisture in the prevailing easterly flow.

1. INTRODUCTION

This paper presents climatological information on the daily liquid equivalent of water vapor in the atmosphere (same as "precipitable water") at a tropical station, and on the daily transport of moisture in the prevailing easterly flow. Observations by the U.S. Navy rawinsonde station at Chaguaramas Bay, a few miles northwest of Port-of-Spain, Trinidad, were used.

The calculations were done in part for an unpublished investigation. The lack of frequency distributions of daily liquid equivalents in the literature prompted the author to complete the set for publication. The cost of reducing the relative humidities and temperatures at numerous levels in radiosonde reports to liquid equivalents up to this time has generally precluded this kind of climatological analysis. As automation lowers costs, meteorological services should increase publication of climatological information on moisture variables. Meanwhile, the limited study here furnishes frequencies unavailable previously of upper-level moisture and transport in a near-equatorial region.

Mean monthly values of liquid equivalent for a network of stations in the United States have been calculated by Reitan [1,2] from mean monthly data. Reitan's work updates an earlier similar analysis by Shands [3]. Shands' paper also contains a table of maximum values of 49 United States stations based on hand inspection of records, and includes most of the old stations taking airplane meteorograph observations (APOBS). Most stations were surveyed from the beginning of record to a date ranging from 1939 to 1943.

The Illinois State Water Survey group computed precipitable water at 12-hr. intervals at three stations surrounding their State and at one station within the State for a 5-yr. period and compared the precipitable water with other weather variables [4]. A classic study on water vapor transport is that of Benton and Estoque [5]. They computed moisture transport at four levels for all observations at a network of stations on the boundaries of the North American Continent for the calendar year 1949 and integrated these transports into monthly, seasonal, and annual values.

2. DATA AND PROCESSING

The basic data consisted of rawinsonde observations at Chaguaramas Bay. Tabulations at standard 50-mb. intervals on WBAN Form 33 were obtained from the National Weather Records Center. The station is at 10°41'N., 61°37'W. at a height of 2 m. above sea level.

Frequency distributions of moisture transport were desired as well as moisture. Therefore, to secure consistent wind observations, the study was restricted to years since the establishment of rawinsonde equipment at the station. The record analyzed comprised the months of January, March, May, July, September, and November from 1954 through March 1961. All available observations at both times of day were processed, the diurnal variation being presumed negligible.

LAYER LIQUID EQUIVALENT

From the temperatures and relative humidities at the standard 50-mb. intervals from 1000 to 500 mb., liquid equivalents are computed by the equation employed by previous investigators:

$$Q=(1/\rho)(6.22Ue_s/p)(\Delta p/g) \quad (1)$$

where

Q=liquid equivalent (cm.)
e_s=saturation vapor pressure (mb.), determined from temperature
p=pressure (mb.), at center of layer
U=relative humidity (percent)
Δp=depth of layer (mb.)
g=acceleration of gravity (cm. sec.$^{-2}$)
ρ=density of water=1.0 gm. cm.$^{-3}$

The density, ρ, often omitted from the liquid equivalent formula, is required for dimensional balance. (If ρ should be omitted, the units of Q, while called cm., would be interpreted not as units of length but as mass per unit area of the same numerical value.) Each standard pressure level represents a 50-mb. layer centered on it (e.g., 500 mb. represents the 525–475-mb. layer), except that 1000-mb. data represent the 1000–975-mb. layer. The space below the 1000-mb. level is ignored. Statistical values of relative humidity, inscribed on the data sheets when humidity is so low that the radiosonde "motorboats," are treated in the calculations in the same way as other relative humidities.

LAYER MOISTURE TRANSPORT

Standard procedures for climatological summaries of moisture transport, a vector quantity, have not yet crystallized. The technique adopted here is to compute the transport in the prevailing easterly flow as the scalar product of wind speed and specific humidity and neglect transports from other directions. Specifically, transport is defined as the product of wind speed and liquid equivalent if the wind direction lies between northeast and southeast, inclusive. Transport is defined as zero for other wind directions. The percentage of winds from the easterly quadrant is listed in table 1. Transports are greatest in the lower levels where the easterly wind is steadiest (fig. 3).

Transports were computed for each layer having a wind from the prescribed easterly quadrant from,

$$M=36\cdot 10^4\rho QV \tag{2}$$

where M=layer moisture transport (gm. cm.$^{-1}$ hr.$^{-1}$), V=speed (m. sec.$^{-1}$), and ρ and Q are the same as in equation (1).

ACCUMULATION THROUGH DEPTH

The layer liquid equivalent and moisture transport values were summed vertically for each sounding. Wind, temperature, or humidity missing at one level only was interpolated from adjacent times and levels. If an item was missing at two or more adjacent levels, calculations were terminated at the last level of data.

NUMBER OF OBSERVATIONS

The number of observations is listed in table 2. The liquid equivalent count exceeds the moisture transport count, a consequence of missing wind observations. For these, liquid equivalent was calculated but the transport had to be omitted. The reference here is to *missing* winds, not *excluded* winds from quadrants other than east.

The distribution of number of observations by years and time of day is shown in table 3 for a typical month.

TABLE 1.—*Percent of winds from eastern quadrant,* Chaguaramas Bay, Trinidad*

Level (mb.)	Jan.	Mar.	May	July	Sept.	Nov.
900	94	98	95	97	89	89
800	93	78	85	96	77	82
700	72	59	80	98	82	80
500	56	48	60	95	83	45

*"Eastern quadrant" includes NE through SE. Period of record is given in table 2.

TABLE 2.—*Number of observations*

Level (mb.)	Jan.	Mar.	May	July	Sept.	Nov.
Liquid equivalent						
900	327	474	427	376	384	353
800	326	471	417	374	375	349
700	326	469	417	374	375	349
500	311	450	407	362	365	335
Moisture transport						
900	277	400	379	334	355	307
800	274	395	369	328	349	303
700	271	388	364	326	347	302
500	254	368	350	321	333	287
Years	1954–57 1959–61	1954–61	1954–60	1954–60	1954–60	1954–60

TABLE 3.—*Number of observations by years and time (GMT) of day. July, 900 mb.*

	Liquid equivalent		Moisture transport	
	0300	1500	0300	1500
1954	23	16	23	14
1955	22	23	11	20
1956	8	7	8	7
	0000	1200	0000	1200
1957	30	31	30	30
1958	21	18	20	15
1959	28	30	21	21
1960	30	31	28	31
1961	29	29	29	26
	191	185	170	164

3. FREQUENCY DISTRIBUTIONS OF DAILY VALUES

Four sets of percentage frequency distributions have been constructed. Liquid equivalents in four selected layers are depicted in figure 1. The liquid equivalents accumulated from 1000 mb. upward to four selected levels are found in figure 2. Frequency distributions of the corresponding layer and accumulated easterly moisture transports appear in figures 3 and 4.

To provide perspective on the degree of saturation associated with the various magnitudes of liquid equivalent, dotted lines marked S have been placed on figures 1 and 2. These denote the saturation liquid equivalent at mean temperature for the period of the study. Some maximum values (100 percent line) do exceed the saturation line by a modest increment and indicate high relative humidities at temperatures higher than the mean.

The salient feature of the graphs is the steadiness of the tropical climate. However, certain variations appear to be related to known weather characteristics of the region. Examples follow.

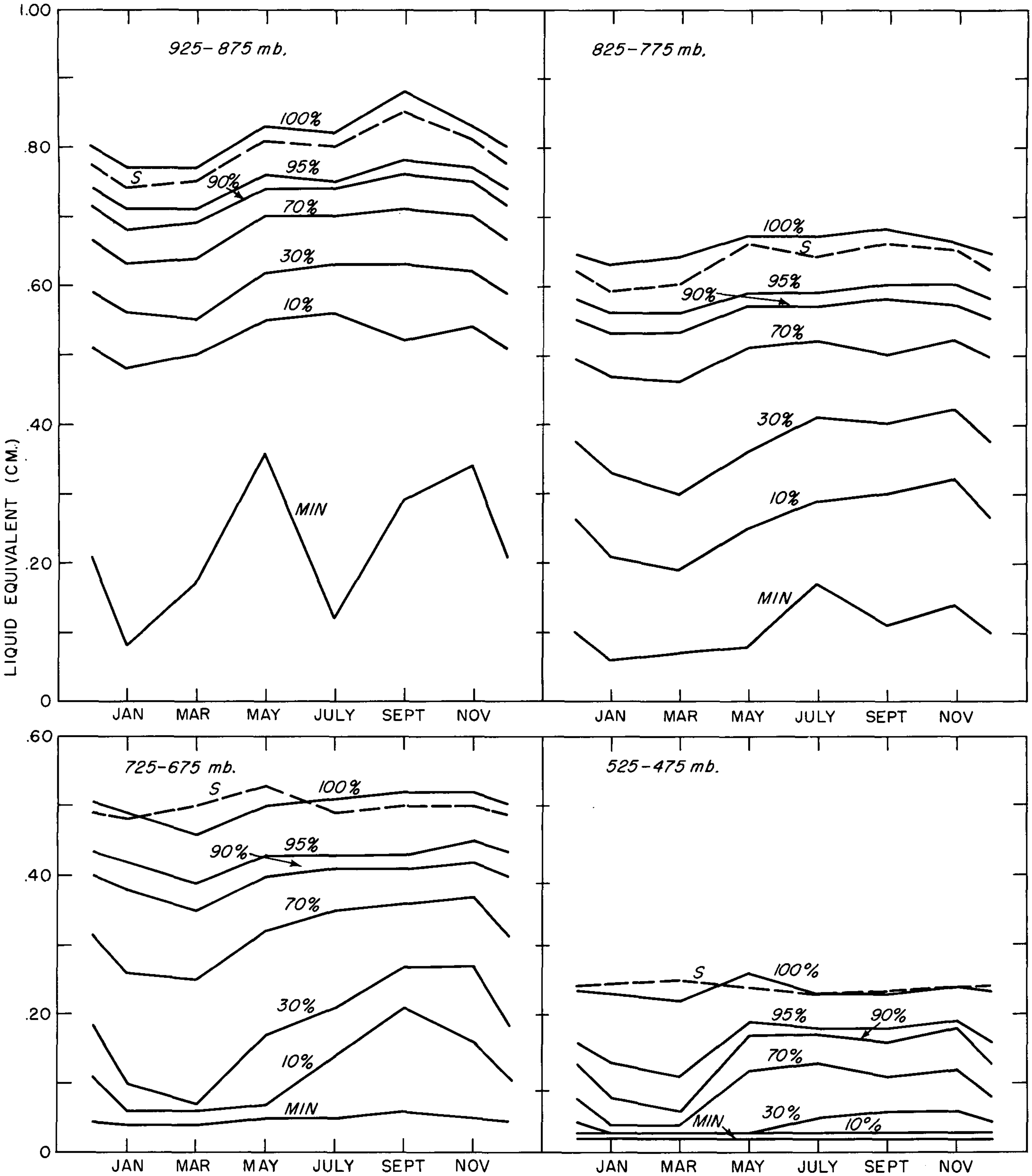

FIGURE 1.—Frequency distribution of liquid equivalent of water vapor in selected 50-mb. layers, Chaguaramas Bay, Trinidad. The liquid equivalent is equal to or less than the amount shown by each curve for the indicated percentage of available observations. S=saturation liquid equivalent at mean temperature.

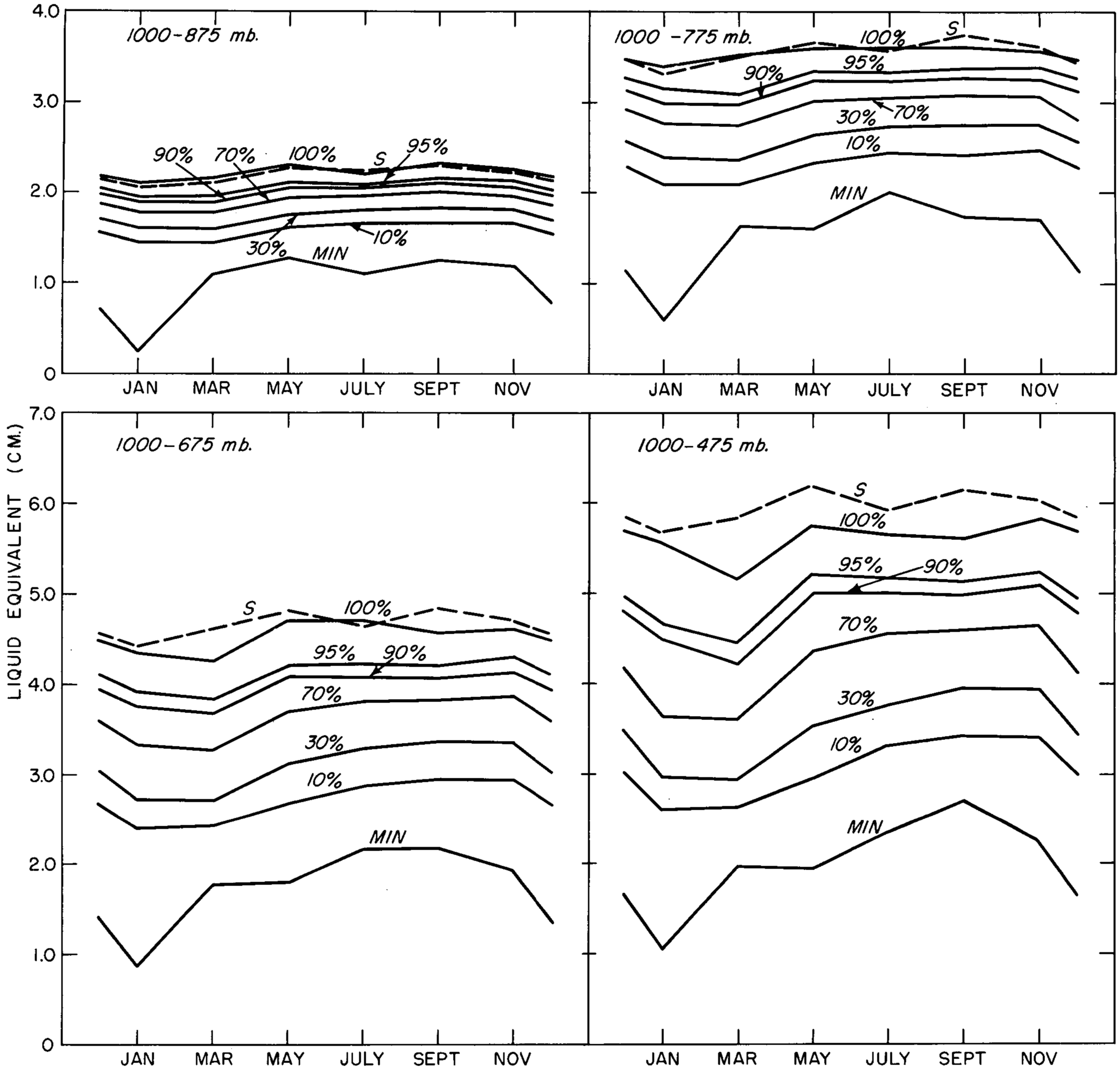

FIGURE 2.—Same as figure 1 for selected deep layers.

March, of the six months analyzed, has the least rainfall and greatest domination by the fair weather trades (table 4). The associated subsidence and low moisture at higher levels is reflected as a dip in March on all graphs from 700 mb. upward and, to some extent, at 800 mb.

Sea surface temperatures in the region of Trinidad reach their highest values in September–October [7]. This is reflected in a September maximum of low-level liquid equivalent (925–875 mb., fig. 1). The maximum shifts to November at upper levels.

TABLE 4.—*Mean monthly precipitation (in.) Port-of-Spain, Trinidad, 1862–1952 (From Wehekind [6])*

January	2.70	July	8.58
February	1.57	August	9.73
March	1.83	September	7.53
April	2.04	October	6.64
May	3.69	November	7.20
June	7.59	December	4.92

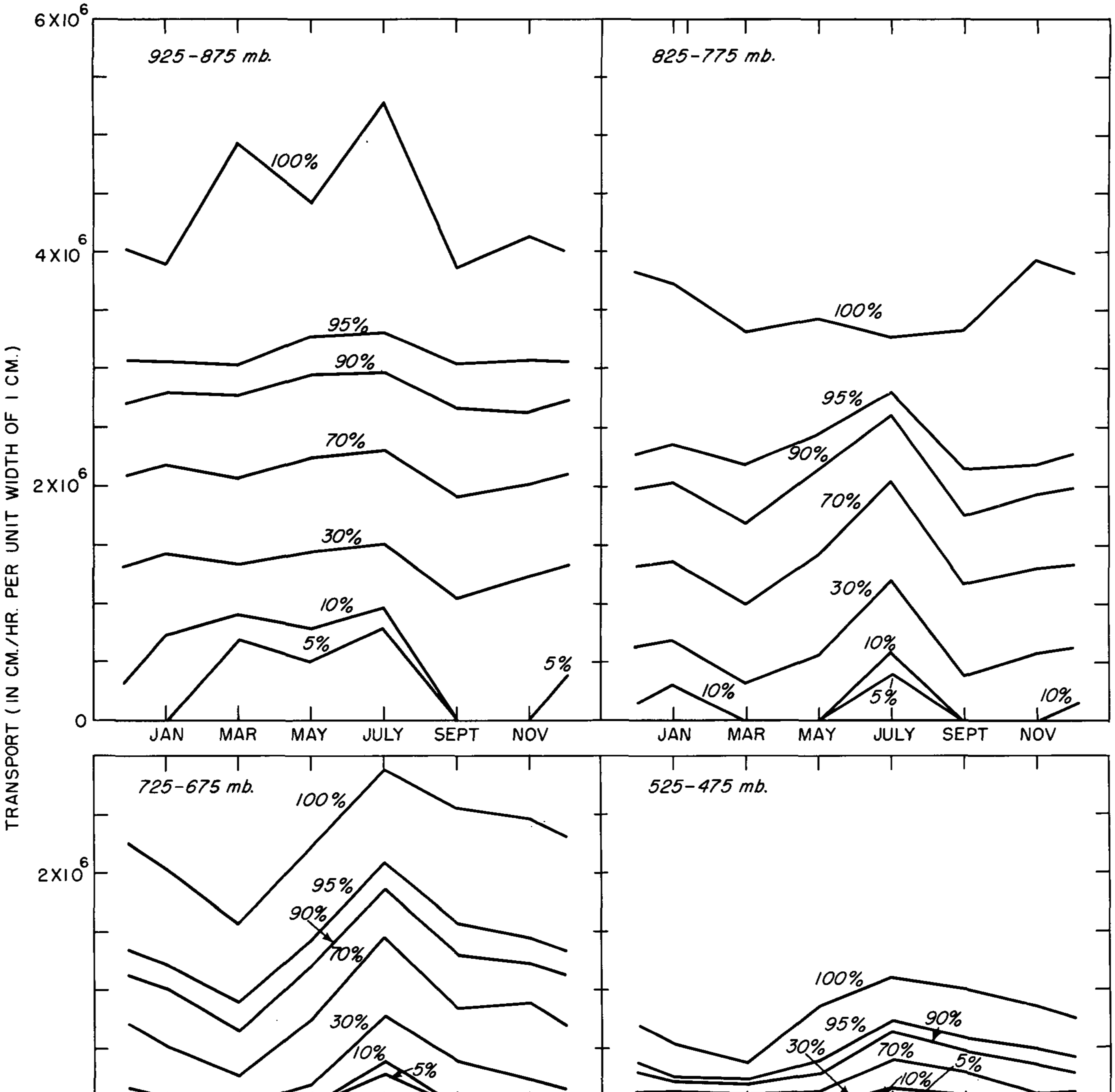

FIGURE 3.—Frequency distribution of moisture transport from eastern quadrant (see text) in selected 50-mb. layers, Chaguaramas Bay, Trinidad. The easterly moisture transport is equal to or less than the amount shown by each curve for the indicated percentage of available observations. Transport is zero where wind is not from eastern quadrant.

There is a distinct upper-level moisture transport maximum in July, (fig. 4). This is the month (of the 6 months analyzed) of greatest convective activity. We would surmise that the high July moisture transport both facilitates high rainfall, and, with the more frequent penetration of convective cloudiness to higher levels, is a result of it. The second peak of rainfall, in November (table 4), we judge in part is associated with easterly waves, rain with lower temperatures at higher levels, and less steadiness of the easterly wind. Thus while the annual peak in moisture at the higher levels appears at this season, there is no secondary peak in the moisture transport from the east.

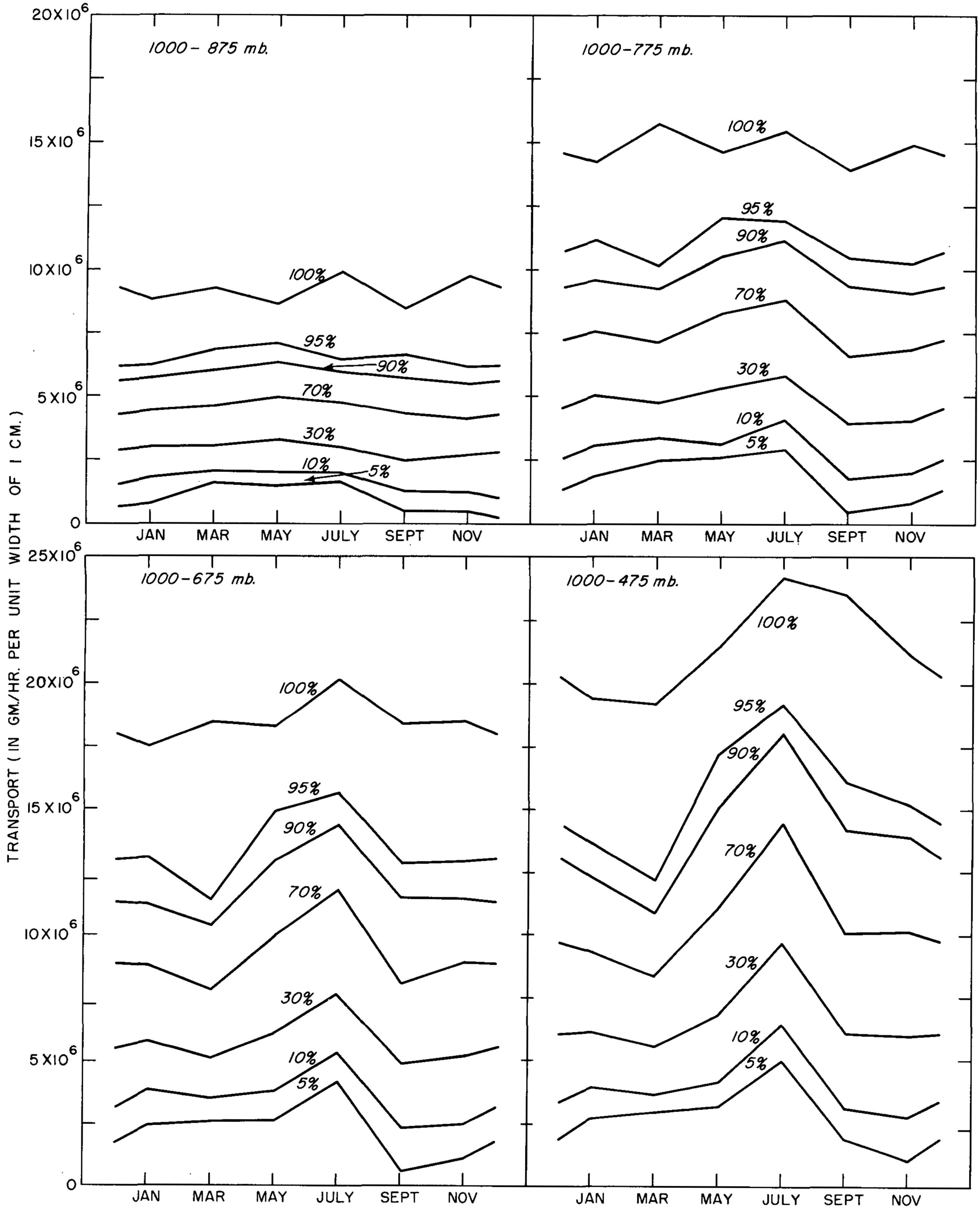

FIGURE 4.—Same as figure 2 for selected deep layers.

Table 5.—*Monthly mean values of liquid equivalent of water vapor (cm.)*

Station	Layer (mb.)	Years	Jan.	Mar.	May	July	Sept.	Nov.	Annual
Chaguaramas Bay, Trinidad	1000–475	1954–61	3.37	3.29	3.95	4.07	4.25	4.26	3.86
Chaguaramas Bay, Trinidad	sfc–325#	1954–61	3.60	3.52	4.25	4.41	4.59	4.70	4.16
Guantanamo Bay, Cuba *	sfc–325	1948–56	2.90	3.18	4.35	4.23	4.67	4.08	3.95
Miami, Fla.*	sfc–325	1946–56	2.31	2.55	3.42	4.53	4.68	3.00	3.44
San Juan, P.R.*	sfc–325	1946–55	3.16	3.04	4.12	4.18	4.57	4.12	3.86

Extrapolated from 1000–475-mb. layer.
* From Reitan [1].

4. MONTHLY MEANS

The daily Trinidad values of vertically-integrated liquid equivalent are averaged into monthly and annual means in table 5. Also listed for comparison are monthly mean liquid equivalents at three other tropical stations, from Reitan [1]. To make the layers the same, the 1000–475-mb. liquid equivalents at Trinidad are extrapolated down to the surface and up to 325 mb. by following trends of monthly mean temperature and relative humidity. The fraction of the total moisture found in these extrapolated layers is insufficeint to warrant processing of daily data at these levels merely for this comparison.

Trinidad has the highest mean annual liquid equivalent of the four stations, but its value exceeds the values of the other three stations during only half the year, November through March. The Guantanamo Bay value is highest in May and the Miami value in July and September, though differences are slight. The annual cycle at Trinidad lags behind that at other stations and, as would be expected farther from polar air sources, is of smaller amplitude.

5. SUMMARY

A climatological presentation has been made of frequency distribution of daily liquid equivalent of water vapor in the atmosphere, and transport of water vapor from the eastern quadrant, at Trinidad, W.I., making available this kind of data at a tropical latitude.

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